Soil monitoring of complex salinization under potash mining

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Abstract

This study was carried out on the territory of Verkhnekamskoe potash deposit in the Lyonva Valley. The Verkhnekamskoe potash mining led to accumulation of large quantities of mining wastes negatively affecting the environment. These wastes are mainly presented by the slurry storage facilities, salt tailing piles and brines. Water-soluble minerals were easily weathered and formed drainage water of the Na–Cl composition that polluted groundwater. As a result of ground water salinization, a substantial transformation of soils was observed around potash mining area and in the river valleys. Two types of the transformed soils were defined in that area: 1) saline alluvial gleyed humus chloride-sodium-magnesium-calcium soil; 2) secondary saline alluvial clay-loam sulfate-chloride-sodium-calcium soil.

Keywords: salinization, soil, groundwater and surface water, environmental monitoring

Introduction

Mining activity is associated with the storage of huge volumes of waste that have a negative effect on the environment. At most potash mines, up to 70% of mined rock is stored on the surface as a wastes (Environmental Aspects of Phosphate and Potash Mining 2001).

The solid halite wastes are deposited as tailings piles, that consist of >95% of NaCl. The fines such as clays and the insoluble fraction in the form of clay-salt slurry and excess brines are pumped to slurry storage facilities. The clay-salt slurry is composed of 35-40% of water-soluble salts and 60-65% insoluble clay material. The high total dissolved solid (TDS) concentration of water streams is due to the high content of soluble salts in the salt tailing piles. Brines infiltrate through the slurry dumps and salt tailings piles into groundwater. Salinization of surface water and groundwater in potash mining regions has been studied by a large number of researchers (Arle and Wagner 2013; Baure et al. 2005; Bel'tyukov 1996; Liu and Lekhov 2013; Lucas et al. 2010).

Other substantial issue is soil salinisation due to rising water tables. Salt accumulation in soil layers occurs when the water tables are shallow (particularly <4 m from the surface) and the groundwater salinity becomes progressively higher due to evapotranspiration. Usually this situation occurs in valley floors of the landscapes in arid ecosystems (Rengasamy 2006; Greene et al. 2016; Fitzpatrick, 2008; Salama et al., 1999).

For the healthy ecosystem functioning, the soil must fully fulfill its ecological functions. Technogenic effect such as salinization couses some changes of the physicochemical properties of soil, that leads to transformation of soil, plant and fauna. The main goal of this paper is to investigate the soil salinization induced by the Verkhnekamskoe potash mining.

Study area

Our studies were carried out on the territory of the Verkhnekamskoe potash deposit in the Lyonva Valley (fig. 1).

The study area is situated on the left bank of the Lyonva River in the vicinity of slurry storage . The slurry storage site came into production in the mid-1970s. A clay-based seal was used to protect groundwater aquifers from contamination. The large amount of precipitation, rugged topography, and cold climatic conditions promote active migration of water-soluble salts into the groundwater.

Effluents seeping through the bed of the slurry storage site were discharged directly into the underlying Quaternary (Q) and Sheshminsky (P1ss) and led to groundwater

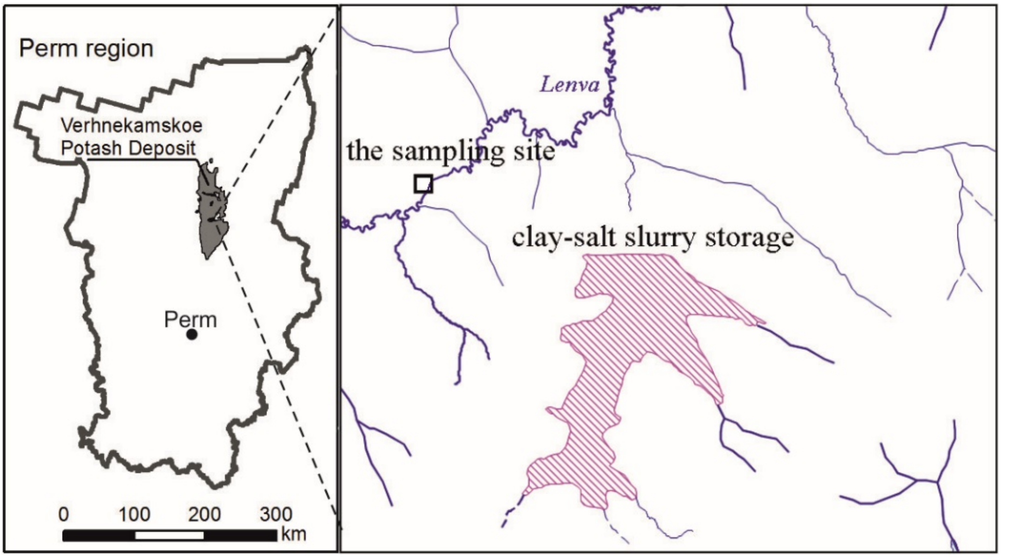

Figure 1. Geographical location and the sampling site.

salinization (Na–Cl type, mineralization of 5.9-29 g/L) (Khayrulina and Maksimovich, 2018). When saline groundwater met confining beds, it seeped to the surface in the river valleys and polluted surface water and soils.

Methods

In seepage areas in the Lyonva River valley, soil samples were taken in soil profile cuts in 2017 year. The morphological and physicochemical methods were used to assess the ecological state of the soil.

Morphological analysis was carried out according to classification and diagnosis of soils of Russia (2004). Physico-chemical analysis of soils included:

- Soil pH was analysed by pH-meter. Soil organic matter was determined by wet-combustion Tyurin method (Theory and practice 2006).
- Soil acidity was determined by the Kappen method, based on treating of soil sample with sodium acetate in concentration 1 mol/dm3 and then titration of soil extract with alkali solution.
- Exchangeable cations was determined by the Kappen-Gilkowitz method, which is processing of soil samples with a certain amount of 0.1 N HCl and then titration of soil extract with 0.1 N NaOH (Theory and practice 2006).
- Cation exchange capacity (CEC) in carbonate samples were determined by the barium chloride method (Theory and practice 2006).
- Mobile phosphates and potassium were determined by Kirsanov method (Theory and practice 2006), based on the extraction of mobile phosphates and potassium from the soil with a solution of 0,2 M HCl. Then mobile phosphates were determined as a blue phosphorus-molybdenum complex on a photoelectrocolorimeter and potassium – on flame photometer (Mineev, 2001).
- The quantity and quality of soluble salts were determined in water extractions of soil samples, followed by determination of anions and cations. Carbonates were determined by back-titration with sulfuric acid; the Na^{+} concentrations in water extraction were determined by flame photometer; and concentrations of Ca^{2+}, Mg^{2+} were determined by titration method with Trilon B (disodium dihydrogen ethylenediaminetetraacetate); sulphate ions calculated as a difference between the amounts of cations and anions (Mineev, 2001).

Result and Discussion

In the floor of the Lyonva River Valley we two transformed soils were observed instead of zonal alluvial humic gley soils. The first type of soils was a saline alluvial gleyed humus chloride-sodium-magnesium-calcium soil consists of three horizonts and covered by vegetation, dominated by the graminaceous and umbrella species. A top 20 cm was a gray-humus horizon AYs,g (colour is gray-brown). It was densely intertwined with roots at the depth of 10 cm, and the roots were rare below 10 cm. The soil colour became darker at the depth of 14 cm and soilstructure was cloddy. A pale gray color and rust-stains were observed from the depth of 18 cm. Gleyed soil Cg was formed in the depth of 20–70 cm. This horizon had a brown colour, rust-stains and iron-manganese nodules. An alluvial gleyed horizon CG with bluy-grey colour and rust-stains was identified from the depth of 70 cm. Then the colour became blue-grey without rust-stain below 100 cm.

Soil chemistry revealed the salt load linked to a high mineralized ground water. The highest ion concentrations (instead of HCO^{3-}) were detected in low horizon at the depth of 70–80 cm (tab. 1). The soil water extract had much higher levels of Cl^- and Na^+.

A second type of transformed soil was secondary saline alluvial clay-loam sulfate-chloride-sodium-calcium soil were formed in the seepage areas in the floor of the Lyonva River Valley. The top layer (≈3 cm) was an iron-bearing crust without any vegetation. A gray-humus horizon AYs (3-15 cm) consisted of black gel-like phasis with a high content of plant residues. A gley loamy horizon G (15-70 cm) had a gray colour with rust-stains

The content of water-soluble ions in the second type of soil substantially exceeded their amount in the first soil. In a layer of 0–3 cm, The maximum content of water-soluble ions was observed (tab. 2) in the top layer of the second type of soil, that decreased slightly with depth. These extremely high ion concetrations are associated with salt water-logging.

The soils were characterized by a high CEC. Its variability depends on the difference in the amount of organic carbon and in the particle size distribution (tab. 3). There was a substantial variation in the content of nutrients, for example, a very high content of potassium and phosphates were detected on the top layer of the second type of soil.

Table 1 *Ion composition of the water extract from the alluvial humus gleyate chloride sodium-magnesium-calcium saline soil.*

Ion	Depth					
(mg/100 g)	5-15 cm	20-30 cm	32-42 cm	50-60 cm	70-80 cm	95-105 cm
Ca^{2+}	76.0	30.0	40.0	96.0	272.0	214.0
Mg^{2+}	20.4	14.4	13.2	30.0	79.2	44.4
Na^+	39.1	29.9	39.1	50.6	108.1	82.8
K^+	7.8	3.9	7.8	7.8	7.8	7.8
HCO_{3-}	11.6	6.1	11.0	51.9	7.9	8.5
Cl^-	330.1	163.3	227.2	379.8	901.7	749.0
SO_{4-}	0	0	0	0	0	0

Table 2 *Ion composition of water extract from the saline secondary sulfate-chloride sodium-calcium*

Ion	Depth		
(mg/100 g)	0–3 cm	5–15 cm	35–45 cm
Ca^{2+}	3260	2080	2180
Mg^{2+}	720	804	1224
Na^+	2500	5451	1699
K^+	9500	46.8	3.9
HCO_3^-	11	26.8	18.3
Cl^-	14420	10167	3226
SO_4^-	8107	5870	9297

Table 3 Physico-chemical properties of researched soils.

Soil name	№	Layer, cm	C_{org}, %	pH_{H2O}	pH_{KCl}	CEC	Soil acidity	P_2O_5 HCl	K_{HCl}
Saline secondary[1]	1	0-3	5.9	5.91	5.84	71.0	2.5	15.7	550
		3-15	5.8	6.75	6.70	37.3	1.1	0.8	150
Alluvial soil[2]	2	0-15	5.4	5.85	5.42	82.7	13.3	3.5	27
Alluvial soil[3]	3	0-15	9.8	5.59	5.19	36.2	7.7	3.8	55
Alluvial soil[4]	4	0-15	1.7	4.31	3.38	64.0	9.4	2.5	15

1 - secondary saline alluvial clay-loam sulfate-chloride-sodium-calcium soil;
2,3 - saline alluvial gleyed humus chloride-sodium-magnesium-calcium soil;
4 – alluvial humus gleyate chloride sodium saline soil.

Conclusions

For the study of the environmental effect of potash mining, the assessment of soil properties is an effective indicator of ecological and geochemical changes in the studied landscapes. The main transformational factor for the soils studied in the river valleys of the Verkhnekamskoye salt deposit is salinization, which was identified throughout the soil profile. As a result of polluted ground water distribution the zonal alluvial humic gley soils were transformed to saline alluvial gleyed humus chloride-sodium-magnesium-calcium soil and secondary saline alluvial clay-loam sulfate-chloride-sodium-calcium soil. The main causes of soil salinization are a mining subsidence and a rising water table.

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References

Arle J, Wagner F (2013). Effect of anthropogenic salinisation on the ecological status of macroinvertebrate assemblages in the Werra River (Thuringia, Germany). Hydrobiologia 701: 129–148

Baure M, Eichinger L, Elsass P, Kloppmann W, Wirsing G (2005). Isotopic and hydrochemical studies of groundwater flow and salinity in the Southern Rhine Graden. Int J Earth Sci 94: 565–579

Bel'tyukov GV (1996). Main sources of contamination of groundwater and surface waters in the area of the Verhnekamskoe potash deposit. Vestnik Permskogo Universiteta (Bull. Perm Univ.), issue 4, Ecology. pp. 128–140.

Classification and diagnosis of soils of Russia (2004) / ed. LL Shishova, VD Tonkonogov, II Lebedeva, MI Gerasimova. Smolensk: Oykumena. 342 p.

Environmental Aspects of Phosphate and Potash Mining (2001). First edition, Paris: United Nations Publication.

Fitzpatrick Rob, Brad Degens, Andrew Baker, Mark Raven, Paul Shand, Margret Smith, Steve Rogers and Richard George (2008). Avon Basin, WA Wheatbelt: Acid Sulfate Soils and Salt Efflorescences in Open Drains and Receiving Environments. In Inland Acid Sulfate Soil Systems Across Australia (Eds. Rob Fitzpatrick and Paul Shand). pp 189-204. CRC LEME Open File Report No. 249. (Thematic Volume) CRC LEME, Perth, Australia.

Greene R, Timms W, Rengasamy P, Arshad M, Cresswell R (2016) Soil and Aquifer Salinization: Toward an Integrated Approach for Salinity Management of Groundwater. In: Jakeman AJ, Barreteau O, Hunt RJ, Rinaudo JD, Ross A (eds) Integrated Groundwater Management. Springer, Cham. Integrated Groundwater Management pp. 377-412.

Kappen H. (1929) Die Bodenazidität. Springer Verlag. Berlin. 363 p.

Khayrulina E, Maksimovich N (2018) Influence of Drainage with High Levels of Water-Soluble Salts on the Environment in the Verhnekamskoe Potash Deposit, Russia. Mine Water Environ 37(3): 595–603.

Liu Y, Lekhov AV (2013) Modeling changes in permeability Characteristics of gypsified rocks accompanying brine flow. Water Resources 40(7): 776-782.

Lucas Y, Schmitt AD, Chabaux F, Clément A, Fritz B, Elsass Ph, Durand S (2010). Geochemical tracing and hydrogeochemical modelling of water–rock interactions during salinization of alluvial groundwater (Upper Rhine Valley, France).

Appl Geochem 25 (11): 1644–1663

Mineev VG (2001) Praktikum po agrohimii. Moscow State University Publ. 689 p.

Motuzova GV, Bezuglova OS (2007) Ecological monitoring of soil. M.: Academic project, Gaudeamus. 237 p.

Rengasamy P. (2006) World salinization with emphasis on Australia. Journal of Experimental Botan, Plants and Salinity (special issue) 57(5): 1017–1023.

Salama RB, Otto CJ, Fitzpatrick RW (1999) Contributions of groundwater conditions to soil and water salinization. Hydrogeology Journal 7:46 – 64.

Theory and practice chemical analysis of soils (Edd. Vorobyova LF). M.:GEOS, 2006. 400 p.

Tyurin IN (1931) Novel transformation of the volumetric method to determine humus using chromic acid. Pochvovedenie. No.5-6, p. 36-47.